

## SECTOR-DIVIDED TURBINE ASSEMBLY WITH AXIAL PISTON VARIABLE-GEOMETRY MECHANISM

### BACKGROUND OF THE INVENTION

#### 1. Technical Field

The invention relates to turbochargers in which a turbine of the  
5 turbocharger is driven by exhaust gas from a reciprocating engine. The invention relates more particularly to turbine housings that are divided into a plurality of substantially separate sections each fed by a separate exhaust system, and to turbochargers having a variable-geometry turbine for controlling the flow into the turbine.

#### 2. Description of Related Art

10 In multiple-piston reciprocating engines, it is known to design the exhaust system in such a manner as to take advantage of the pressure pulsation that occurs in the exhaust stream. In particular, it is known to employ what is known as "pulse separation" wherein the cylinders of the engine are divided into a plurality of  
15 subgroups, and the pulses from each subgroup of cylinders are substantially isolated from those of the other subgroups by having independent exhaust passages for each subgroup. To take best advantage of pulse separation, it is desired to minimize the communication or "cross talk" between the separate groups of cylinders. Accordingly, in the case of a turbocharged engine, it is advantageous to  
20 maintain separate exhaust passages all the way into the turbine of the turbocharger. Thus, the turbine housing into which the exhaust gases are fed is typically divided into a plurality of substantially separate parts.

There are basically two ways in which turbine housings have been divided: (1) meridional division, and (2) sector division. In a meridionally divided turbine housing, the generally annular volute or chamber that surrounds the turbine wheel and into which the exhaust gases are fed is divided into a plurality of passages in the meridional plane such that each passage occupies a full circumference and the passages succeed each other in the axial direction, such as shown in Figure 4 of U.S. Patent No. 4,027,994.

The present invention relates instead to sector-divided turbine housings. In a sector-divided turbine housing, the generally annular chamber is divided into angular sectors each of which occupies only a part of the circumference such that the passages succeed each other in the circumferential direction, such as shown in Figure 2 of U.S. Patent No. 6,260,358. That figure also shows guide vanes 12 that are positioned just radially inwardly of the chamber and guide the flow into the turbine wheel.

To optimize the performance of a turbocharger over a range of different engine operating conditions, it is also desirable to control the flow through the turbine by using a variable-geometry mechanism so that the turbocharger can operate at a more-advantageous operating point as the reciprocating engine speed and other variables change. The problem addressed by the invention is the integration of both sector division and variable geometry in a turbocharger. In known prior turbochargers having sector division and variable geometry, the full benefits of sector division generally have not been achieved; in fact, the benefits of sector division and variable geometry each have been compromised when such integration has been attempted.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is an axial cross-sectional view of a turbocharger in accordance with one embodiment of the invention;

FIG. 2 is a sectioned view of a turbine assembly in accordance with one embodiment of the invention;

5           FIG. 3 is a sectioned view of a turbine housing of the turbine assembly;

FIG. 4A is an exploded perspective view of a vane and piston assembly of the turbine assembly;

FIG. 4B is a cross-sectional view through the piston along line 4B-4B in FIG. 4A;

10           FIG. 4C is a perspective view of the vane and piston assembly, with the piston in a relatively open position with respect to the vanes;

FIG. 4D is a view similar to FIG. 4C, showing the piston in a relatively closed position;

15           FIG. 5 is a view similar to FIG. 4D, showing an alternative embodiment in accordance with the invention;

FIG. 6 is an axial cross-sectional view of a turbine assembly in accordance with yet another embodiment of the invention; and

FIG. 7 is a perspective view of the piston included in the turbine assembly of FIG. 6.

20           DETAILED DESCRIPTION OF THE INVENTION

The present inventions now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth  
25   herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

FIG. 1 illustrates a turbocharger 10 in accordance with one embodiment of the invention. The turbocharger 10 is similar in many respects to that described in U.S. Patent No. 5,441,383, which is incorporated herein by reference. The major components or modules of the turbocharger include a compressor assembly 20, a center housing and bearing assembly 30, and a turbine assembly 40. The compressor assembly 20 comprises a compressor housing 21 that defines an axially extending air inlet 22 through which air to be compressed is received into the compressor assembly. Mounted within the compressor housing is a compressor wheel 23 that is rotatable about a central longitudinal axis of the turbocharger. The compressor wheel 23 is mounted on one end of a rotatable shaft 26 that extends longitudinally through the center housing and bearing assembly 30 and connects to the turbine as described below. The compressor wheel supports a plurality of compressor blades 24. The housing 21 and the wheel 23 define a flow path therebetween, and the blades 24 occupy the flow path. The flow path is oriented generally axially at an upstream side of the compressor wheel, and then turns radially outwardly so that it extends generally radially outwardly at a downstream side of the wheel adjacent the trailing edges of the blades 24. Air is ingested through the inlet 22 into the row of blades 24 and is compressed as it travels along the flow path through the compressor; the compressed air is discharged radially outwardly into a generally annular volute 25 defined by the compressor housing. From the volute 25, the compressed air is supplied via a discharge pipe (not shown) to an engine with which the turbocharger is associated. Compressing the intake air allows a greater amount of power to be produced by the engine. The compressor illustrated in FIG. 1 is generally referred to as an axial-radial compressor, or a centrifugal compressor; however, the invention is not limited to any particular type of compressor, and other types may be used, such as axial-flow compressors.

The center housing and bearing assembly 30 includes a center housing 31 having a central bore therethrough, coaxially arranged with respect to the rotational axis of the compressor wheel. A bearing 32 is mounted within the bore of the center housing. The bearing 32 defines a central bore therethrough, and the shaft

26 extends through the bore in the bearing. There is a radial clearance between the shaft and the bearing bore so that the shaft can rotate with respect to the bearing; oil or other lubricant is supplied into the bearing assembly via a supply port 33 defined in the center housing, and from the port 33 to the bearing via passages 34, 35, 36. The oil that has lubricated and cooled the bearing assembly is drained from the center housing via a drain 37. Although an oil-lubricated bearing system is shown, the invention is not limited to any particular type of bearing system.

The turbine assembly 40 includes a turbine housing 41 that defines a central cylindrical bore 42 therethrough. The turbine housing also defines a generally annular volute or chamber 43 that surrounds the central bore 42 and opens into the bore at a radially inner side of the chamber. Mounted on the opposite end of the shaft 26 from the compressor wheel 23 is a turbine wheel 44 that supports a plurality of turbine blades 45. In a typical installation of the turbocharger, hot exhaust gas from the engine (not shown) is supplied via a suitable exhaust duct system (not shown) into the chamber 43. The exhaust gas flows generally radially inwardly (although it can also have an axial component) from the chamber into the row of turbine blades 45, which are appropriately shaped so that the turbine wheel 44 is rotatably driven by the exhaust gas. The exhaust gas is expanded to a lower pressure as it passes through the turbine, and is then discharged from the turbine housing 41. Mechanical power generated by the turbine is used to drive the compressor via the shaft 26.

As previously noted, it is advantageous to design a reciprocating engine's exhaust system in such a manner as to take advantage of the pressure pulsation that occurs in the exhaust stream. In particular, it is known to employ what is known as "pulse separation" wherein the cylinders of the engine are divided into a plurality of subgroups, and the pulses from each subgroup of cylinders are isolated from those of the other subgroups by having independent exhaust passages for each subgroup. To take best advantage of pulse separation, it is desired to minimize the communication or cross talk between the separate exhaust passages. Accordingly, in the case of a turbocharged engine, it is advantageous to maintain separate

exhaust passages all the way into the turbine of the turbocharger. To this end, the turbine housing 41 of the turbocharger advantageously comprises a sector-divided turbine housing, wherein the generally annular chamber 43 is divided into a plurality of angular sectors that are separate from one another and are fed with exhaust gas via separate inlet ducts. Various numbers of sectors can be employed in accordance with the invention.

FIGS. 2 and 3 depict one embodiment of a turbine assembly and housing wherein the generally annular chamber 43 is divided into two angular sectors 43a and 43b each occupying approximately 180 degrees of the circumference of the chamber. The chamber 43 is divided into the sectors by a pair of dividing “tongues” or walls 46 that extend generally radially inwardly (but typically also with a substantial circumferential or tangential directional component) from a radially outer wall of the chamber. The sector 43a is supplied with exhaust gas via an inlet duct 47a, and the sector 43b is supplied with exhaust gas via a separate inlet duct 47b.

As the operating condition of the engine changes, it is desirable to be able to control the flow rate through the turbine. With reference to FIGS. 1 and 2, the exhaust gas in each sector 43a,b flows radially inwardly to the turbine wheel 44 via a variable-geometry turbine nozzle. The variable-geometry turbine nozzle is provided by a hollow cylindrical or tubular piston 48 that is arranged to slide axially within the bore 42 of the turbine housing 41 between a relatively open position (shown in phantom lines in FIG. 1) and a relatively closed position (shown in solid lines in FIG. 1). In the relatively open position, the piston uncovers a relatively large proportion of the total axial length of the chamber sectors 43a,b so that a relatively large flow area is available for the exhaust gas to flow through as it flows inwardly to the turbine wheel. In the relatively closed position, the piston 48 covers a substantial portion of the axial length of the sectors so that a relatively small proportion of the axial length is available for the exhaust gas to flow through. The piston is moved between the open and closed positions by a suitable actuator and control system (not shown); advantageously, the actuator

and control system are also operable to position the piston in any axial position between the fully open and fully closed positions, so that an infinitely variable adjustment of the variable-geometry turbine nozzle can be achieved.

The turbine assembly 40 also can include a vane arrangement 50 for  
5 guiding the flow into the turbine wheel. In accordance with the present invention, the vane arrangement, the variable-geometry turbine nozzle, and the sector division of the turbine housing are combined in a unique and particularly advantageous way. With reference to FIGS. 1-4, the vane arrangement includes a generally ring-shaped member 51 that abuts the turbocharger center housing 31 and includes a  
10 flange retained between the center housing 31 and the turbine housing 41. A plurality of vanes are mounted on the member 51 and project from one side thereof; the vanes are radially located just inward of the turbine housing chamber 43, as best seen in FIG. 1. The vanes include dividing vanes 52 that are arranged to abut or join with, in a substantially sealed manner, the radially inner ends of the  
15 dividing walls 46 of the sector-divided turbine housing. The dividing vanes 52 thus serve as extensions of the dividing walls so that the sector-division of the turbine housing is extended all the way to the trailing edges of the dividing vanes, and hence essentially to the turbine wheel 44. The vane arrangement also optionally includes one or more additional vanes 53 arranged between the dividing  
20 vanes 52. In the embodiment of FIGS. 1-4, there are three additional vanes 53 per sector 43a,b, and the additional vanes have a smaller axial extent than the dividing vanes. However, it is within the scope of the invention to eliminate the additional vanes altogether so that the only vanes present in the turbine are the dividing vanes.

25 The dividing vanes can extend across the full axial length of the turbine housing sectors 43a,b as seen in FIG. 1, so that the sector-division of turbine housing is preserved when the piston 48 is in the fully open position. The additional vanes 53, on the other hand, can extend across less than the full axial length of the sectors 43a,b. In the illustrated embodiment, the vanes 53 are sized  
30 so that when the piston 48 is in its most closed position as shown in FIG. 1, the

vanes 53 extend across the remaining open portion of the sectors 43a,b; in this closed position of the piston, the vanes 53 can abut the end of the piston.

It will be noted that the vanes radially overlap the piston 48. Accordingly, the piston has a slot 49 for receiving each dividing vane 52. The slots 49  
5 advantageously fit closely about the dividing vanes 52 so that flow is substantially prevented from passing between the dividing vanes and the slots from one sector of the turbine housing chamber to an adjacent sector. In this manner, the sector-division of the turbine housing can be preserved all the way to the trailing edges of the dividing vanes for all positions of the piston. As shown, the slots 49 for the  
10 vanes 52 extend generally radially inwardly into the piston from the radially outer side of the piston, but it is preferred (although not essential) for the slots not to go all the way through to the radially inner side of the piston; that is, the slots preferably extend through less than the full radial thickness of the piston.

The invention is not limited to turbocharger arrangements in which the  
15 additional vanes are shorter than the dividing vanes. FIG. 5 shows an alternative embodiment of a vane assembly 50' and piston 48' wherein the dividing vanes 52' and additional vanes 53' are all the same length and are sized to extend across the full axial length of the turbine housing sectors. The piston includes slots 49' for the dividing vanes and also includes slots 49'' for the additional vanes 53'. With  
20 this arrangement, the vanes provide a guiding function at all positions of the piston.

It is also within the scope of the invention to mount the vanes on the piston so that the vanes travel with the piston. FIGS. 6 and 7 depict such an embodiment. FIG. 6 shows a turbine assembly 140 generally similar to the turbine assembly 40 of FIG. 1, including a sector-divided turbine housing 141, a turbine wheel 144, and  
25 an axially sliding piston 148. Dividing vanes 152 and additional vanes 153 are affixed to the end of the piston 148 and project axially therefrom. The dividing vanes are longer than the additional vanes, and are long enough so that when the piston is in its most open position (as shown in phantom lines in FIG. 6), the dividing vanes extend across the full axial length of the turbine housing sectors  
30 143. The turbine assembly includes a heat shroud 160 that is retained between the

center housing 31 and the turbine housing 141 and forms one wall of the turbine nozzle passage through which the exhaust gas flows into the turbine wheel. The heat shroud includes slots 161 through which the dividing vanes extend when the piston is moved toward its closed position as shown in FIG. 6. Although the  
5 additional vanes 153 are described and shown as being shorter than the dividing vanes 152, it is within the scope of the invention to make the additional vanes the same length as the dividing vanes, in which case the heat shroud 160 would include slots for the additional vanes as well as the dividing vanes.

Thus, in turbine assemblies embodying concepts of the present invention,  
10 the dividing vanes either can be mounted on the piston and be received through slots in a fixed structure of the turbine assembly, or can be mounted on a fixed structure of the turbine assembly and be received through slots in the piston. It is also possible for the dividing vanes to be formed integrally with (i.e., of one piece with) the dividing walls; for example, the turbine housing can be cast, and the  
15 dividing walls and dividing vanes can form integral parts of the casting. Any additional vanes included in the vane arrangement can also be mounted either on fixed structure or on the piston; additionally, it is possible to mount the dividing vanes on fixed structure and mount the additional vanes on the piston, or to mount the dividing vanes on the piston and mount the additional vanes on fixed structure.

20 The disclosed embodiments of the invention all include additional vanes in addition to the dividing vanes. However, it is within the scope of the invention to employ dividing vanes alone, with no additional vanes. It is also within the scope of the invention to provide any number of additional vanes per sector of the turbine housing. Furthermore, although the disclosed embodiments all have only two  
25 sectors, the invention is not limited to any particular number of sectors, and three or more sectors may be employed. Turbine assemblies in accordance with the invention can also include an integrated bypass (not illustrated) arranged in the variable-geometry piston such that when the piston is in a particular position (e.g., its fully open position), the bypass allows the exhaust gas in the turbine housing  
30 chamber to bypass the turbine wheel and thereby achieve an augmented flow rate.

Moreover, while the pistons in the illustrated embodiments are shown as not extending radially inwardly beyond the trailing edges of the vanes, it is within the scope of the invention to have the piston extend radially inwardly of the vane trailing edges.

5           It will also be noted that the disclosed embodiments have turbine wheels in which the inlet and exit diameters of the wheel are the same. However, the invention is not limited to such configurations, and it is within the scope of the invention to employ turbine wheels of other configurations. For example, the turbine wheel can have an exit diameter smaller than its inlet diameter.

10           Additionally, the invention is not limited to radial-flow turbines as illustrated, but also applies to mixed-flow and axial-flow turbines. In a mixed-flow turbine, the exhaust gas enters the turbine wheel along a direction having both radially inward and axial components. Accordingly, the gas flows from the generally annular chamber in a generally radially inward direction and can then be  
15           turned somewhat toward axial by suitable guide vane extensions just upstream of the turbine wheel. In principle, however, the concepts of the present invention still apply to mixed-flow arrangements. Similarly, the invention also applies to axial-flow turbines, wherein the flow leaving the generally annular chamber is turned just upstream of the turbine wheel by suitable guide vanes so that the flow enters  
20           the wheel generally axially.

          Based on the foregoing, it will be recognized that the invention provides a unique and particularly advantageous uniting of sector-division and variable-geometry turbine nozzle features in a turbine assembly for a turbocharger or other device. By virtue of the invention, the sector-division of the exhaust streams from  
25           an engine can be kept separate and essentially isolated from one another all the way to the inlet of the turbine wheel. At the same time, the full benefits of variable geometry are attainable.

          Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain

having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims.

- 5 Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.